Original Article

AN ENERGY-EFFICIENT ELECTROCHEMICAL PROCESS FOR THE EXTRACTION OF COPPER FROM SCRAP ELECTRICAL AND ELECTRONIC CIRCUIT

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Abstract

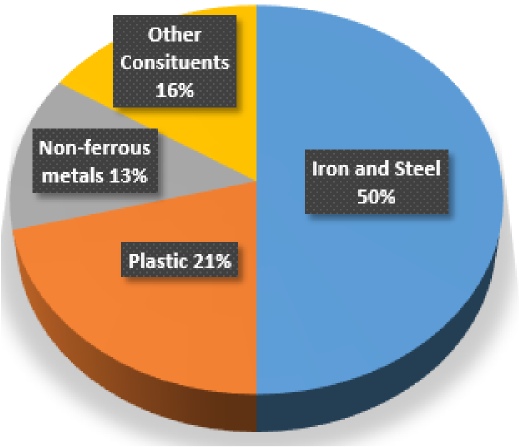
Increase in the productivity and demand of electrical and electronic products (EEP) gives rise to the scrapped e-waste. Due to the existence of heavy metals in the discarded EEP, the scrap needs to be disposed properly to avoid any environmental damage. This rate of rise of e-waste is high enough to grab the attention of researchers and pollution control boards of respective countries for the proper disposal & recycling of the waste. An evolution in development of sustainable and environment friendly technology for extraction of metals from the waste scrap has started with electrochemical, pyrometallurgical, hydrometallurgical and bioleaching process. The paper illustrates an electrolysis process for the extraction of Cu. In this research work electrolysis process is carried out with a various combination of electrodes and electrolytes for achieving the maximum extraction efficiency of Cu. In this process of electrolysis, 99% extraction efficiency of Cu is achieved.

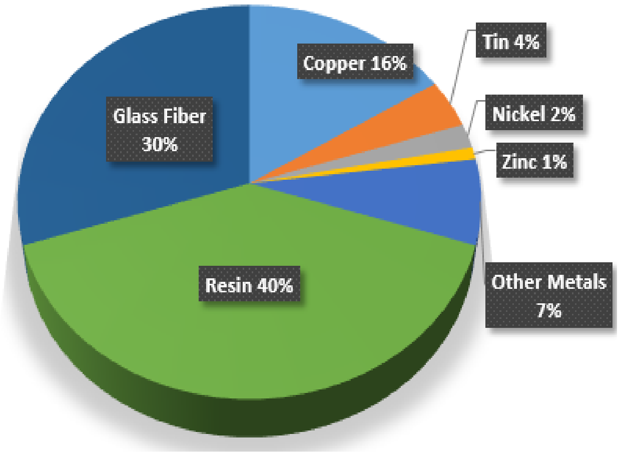
Keywords: Electrolysis, Energy model, E-waste, Electrochemical, PCB boards.

Introduction

A roaring demand in the utilization of EEP in the 20th century engendered the scrapped electrical and electronic products. Presently only 20% of the E-Waste is recycled globally. The world produces 50 million tonnes of e-waste in a year that can raise to 120 million by 2050 [1][2][3]. The illegal dumping or incineration of the waste can contaminate the soil, air and water [4] [5] as near about 1000 toxic substances [6] are present in the scrapped materials. Even though e-waste is categorized as hazardous waste, there is enough potential for value recovery. E-waste accommodates an extensive variety of components, steel and iron, the foremost material found in the waste which consist nearly half of the entire weight of the waste followed by plastics, non-ferrous metals and other constituents like rubber, concrete and ceramics [7] [8] as shown in Fig. 1(a).

Fig. 1: (a) Distinguished Combination of materials in E-Waste (b) Different components in PCB Board





In electrical and electronic circuits several conductive materials like Copper, Silver, Aluminium, Gold, Steel, Iron and several other metals are frequently used. The printed circuit board (PCB) is used as the platform where all the semiconductor chips, capacitors and resistors are mounted. The constituents of PCBs are epoxy resin, fibreglass, copper, nickel, Zinc, Tin other metals which consists of precious metals like Gold, Silver etc. as shown in Fig. 1(b). Materials and metals mentioned above along with the electronic parts are mounted to the board using a solder containing lead and tin [9]. The PCB formed after the amalgamation has an approximate composition of 40% metals, 30% ceramics and 30% plastics [10-11]. On the other hand, the concentration of precious metals such as gold and palladium in waste PCBs are higher than that found in natural ore. On that account recycling of PCBs is beneficial both economically and environmentally [12] thus extraction of precious metals and other non-ferrous metals from PCB Boards are at greater priority. Several methods like electrochemical [13], pyro-metallurgical, hydrometallurgical and bioleaching [14][15][16][17][18] are employed to extract non-ferrous metals from the waste PCB boards. Among all the methods electrochemical techniques have attracted giant interest for the extraction of metal due its environmental compatibility, higher efficiency, and high purity of extraction [19][20]. Research reported [21][22][23] that the extracted Cu purity can reach up to 99.3% using the concentration 30 g/l $CuSO_4.5H_2O$, 60 g/l NaCl, 150 g/l H_2SO_4 with the current density of 80 mA/cm^2. Another research reported 97.6% purity of Cu recovered using electro kinetic method [19] for extraction of Cu. Various Literatures available regarding electrodes used for extraction of copper in which it shows best recovery rate 95% with using copper sheet as a cathode [24][25][26].

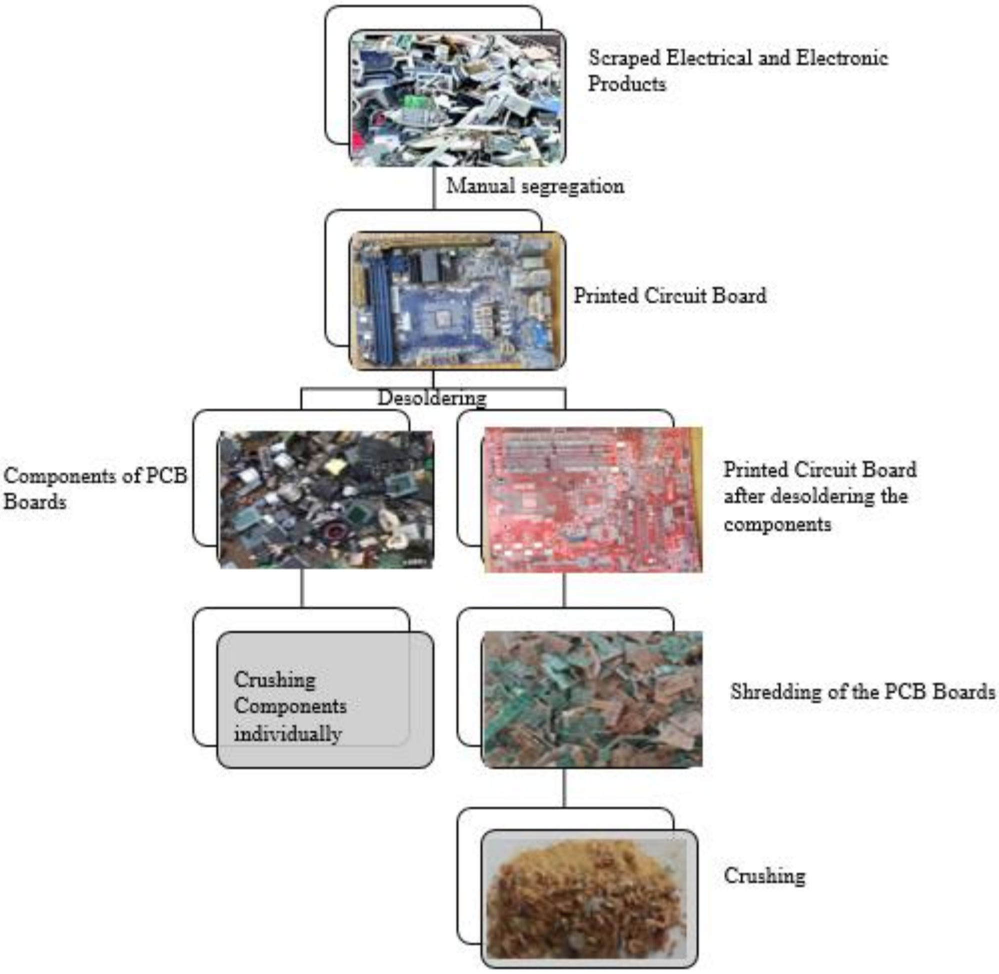
In this research work two different PCB from motherboards were used to extract first Cu along with other metals. Later an electrochemical method was used to selectively separate copper from the solution of metals. Three different solvents mixture were used to extract metals and same were used as an electrolyte for further electrolysis.

Materials and methods

Sample Preparation:

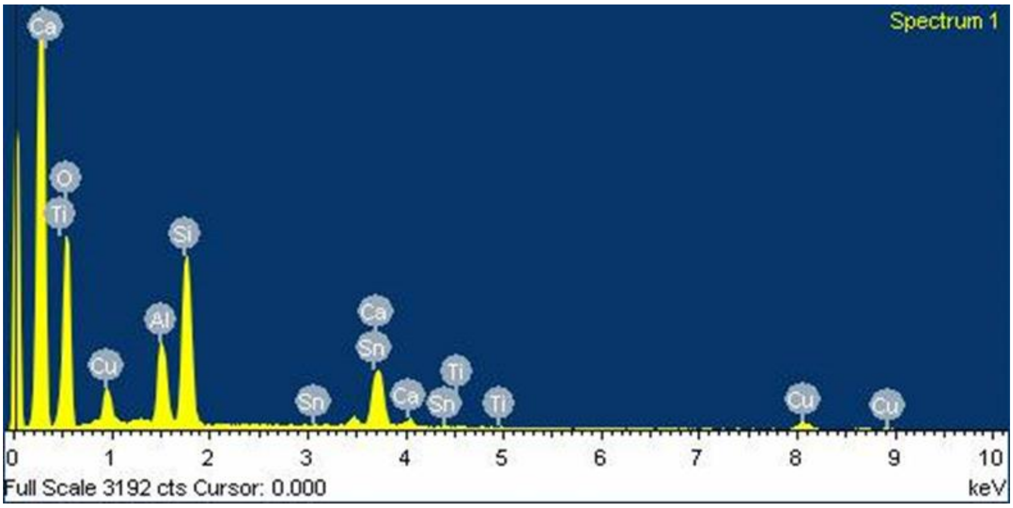
The PCB of both types were first the pre-treated separately by a series of physical processes as shown in Fig. 2 which includes dismantling of the components, shredding and crushing of the components to 1-2 mm of the size. Further, Electrostatic separator was used to segregate ferrous and non-ferrous metals.

Fig. 2: Pre-treatment of PCB Boards



The electrolyte was prepared based on the non-ferrous metals to be extracted. A 10 gm grinded sample of waste PCB powder was taken for extraction experimental purpose and dissolved with various solvents which were also used as electrolytes for the electrolysis experiments. Metal detection in the metal powder was found by X-ray spectroscopy (EDS) as shown in Fig.3.

Fig. 3 EDS Analysis of metal powder



The AAS (Atomic Absorption Spectrophotometer) Analysis of the leached solution is done using Shimadzu AA-7000 instrument to check the amount of metals present in the sample. The analysis report is shown in Table 1. It shows clearly that the prime metal present in both the sample is Copper as shown in the table 1.

Table 1: AAS Analysis of different samples

ITEM	**METALS (mg/L)**							
	COPPER	**ZINC**	**NICKEL**	**CHROMIUM**	**MANGANESE**	**LEAD**	**CADMIUM**	**IRON**
printed circuit board of xerox machine	**10882.322**	**278.9742**	**172.9434**	**6.5826**	**8.3524**	**237.8011**	**0.4481**	**238.3379**
Pentium 4 motherboard	**11955.227**	**564.0118**	**200.0534**	**7.5964**	**6.2476**	**133.9137**	**0.6406**	**251.9072**

Electrolyte Preparation

Electrolyte was prepared by testing several combinations of electrolyte which gives the better leaching of copper in the electrolyte medium.

Case 1:

For the preparation of electrolyte 10gm of E-Waste powder was stirred in 1 mole of H_2SO_4 and 1 mole of HCl for 6 hours at a speed of 300 rpm at 60^0.

$H_2SO_4 + HCl \rightarrow H_2O + Cl_2 + SO_2$ (1)

$Cu + Cl_2 \rightarrow CuCl_2$ (2)

$CuCl_2 + H_2SO_4 \rightarrow CuSO_4 + HCl$ (3)

Case 2:

For the preparation of electrolyte 10gm of E-Waste powder was stirred in 1 mole of HNO_3 and 1 mole of NaCl for 6 hours at a speed of 300 rpm at 60^0.

$HNO_3 + NaCl \rightarrow NaNO_3 + HCl$ (5)

$Cu + 2NaNO_3 \rightarrow Cu(NO_3)_2 + 2Na$ (6)

Case 3:

In this case the electrolyte was prepared by dissolving 10gm of E-Waste powder in 1 mole each of H_2SO_4 , H_2O_2 and 1 mole of HCl for 6 hours at a speed of 300 rpm at 60^0.

$H_2SO_4 + HCl \rightarrow H_2O + Cl_2 + SO_2$ (7)

$Cu + Cl_2 \rightarrow CuCl_2$ (8)

$2CuCl_2 + 2H_2O_2 \rightarrow 4HCl + 2CuO + O_2$ (9)

Electrolysis

Various diversified electrolysis cells have been developed for extraction of metals from electrolytes in different studies [20] [21] [24]. The reactor cell was fabricated with dimensions of glass (12 cm × 8 cm × 7cm , 672 cm^3) developed in the laboratory for experiments. The anode and cathode chambers were separated by an anti-acid filter cloth. The rector was designed to accommodate up to one liter of electrolyte solutions. Selection of electrodes depends on the metals to be recovered. Several experiments were carried out in order to check the best combination of electrodes to extract copper from the electrolyte solution. A DC (0-30)V DC source was connected to apply the potential between the electrodes. The potential was found using Nernst equation number (10)

$$E^0_{Cell} = \frac{RT}{nF\ln(K)} = \frac{0.0592}{n}\log(K) \tag{10}$$

where, R=universal Gas Const. = 8.314472 $JK^{-1}mol^{-1}$, T is Temperature= 28^0 c = 298 k, F is Faraday's constant= 9.6485 * 10^{-4} C mol^{-1}.

$$E^0_{Cell} = E^0_{Cathode} - E^0_{Anode} \tag{11}$$

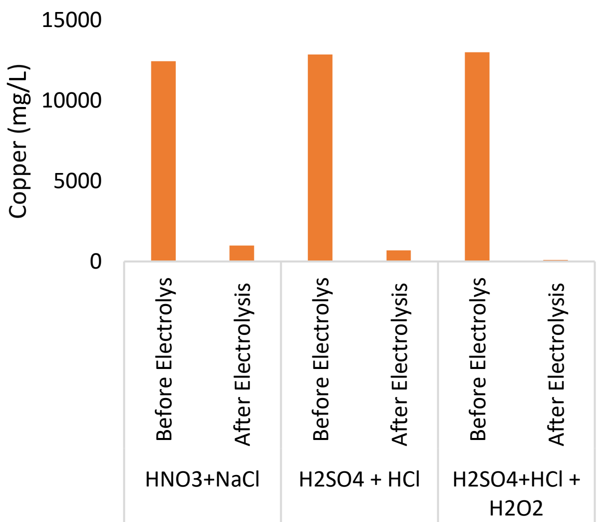
Equation number (11) gives the potential of the cell which is the difference between Reduction Voltage ($E^0_{Cathode}$) and Oxidation Voltage (E^0_{Anode}). The equation (11) was solved and the rectifier is set to 0.554 V in order to extract copper from the electrolyte solution.

Results and Discussion

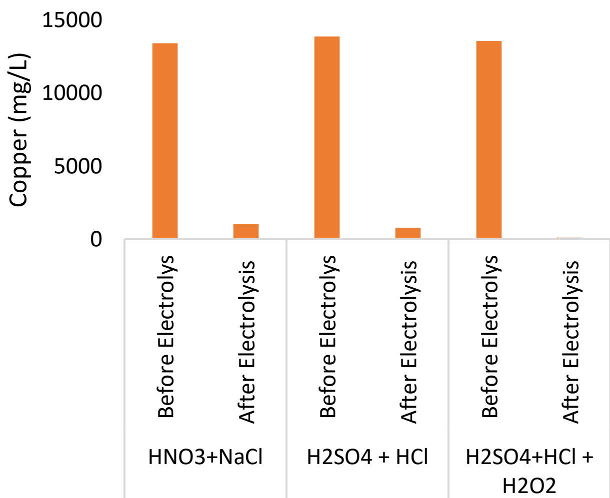
Electrolyte

As described in section 2.2 various combinations of electrolytes were used to get more leaching and extraction efficiency of Cu as shown in Fig. 4. It is obvious from the Fig. that more leaching of Cu in the electrolyte solution when H_2SO_4, HCl and H_2O_2 were used as the electrolyte medium. The whole process was carried at 60^0C temperature and at a stirring speed of 300 rpm.

Fig. 4: Different electrolytes used for extraction of copper (a) printed circuit board of xerox machine, (b) Pentium 4 motherboard



(a)

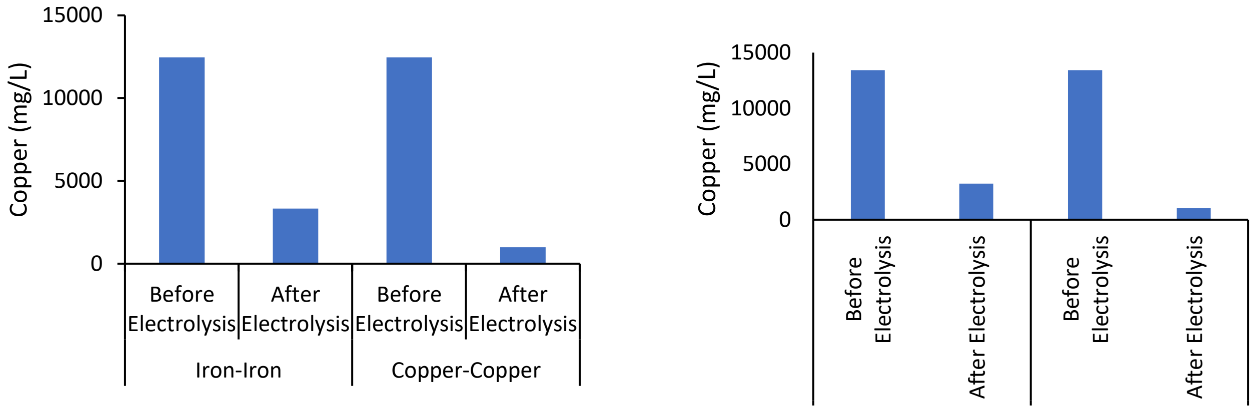


(b)

Electrodes

Electrolysis process was carried out by two combinations of electrodes to achieve the maximum extraction efficiency of copper as shown in Fig. 5. It clearly describes the better extraction of Copper when Cu strip was used as both anode and cathode compare to the Iron strip as anode and cathode.

Fig. 5: Deposition of copper at cathode and remaining copper in the solution for cathode and anode iron-iron and copper-copper(a) printed circuit board of xerox machine, (b) Pentium 4 motherboard

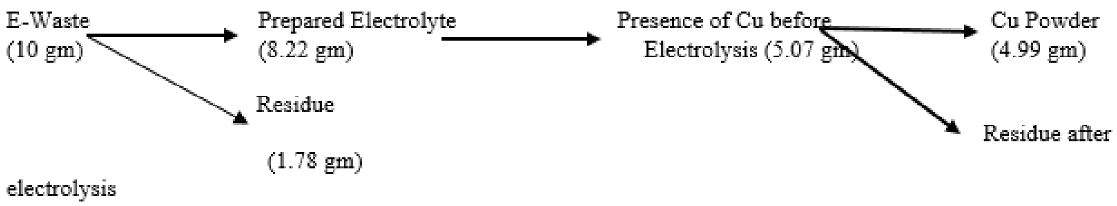


(a) (b)

Material Balance

Material balance is done at every step and summarized in Fig 7. Initially 10 gm of waste PCB sample was taken for analysis and finally 4.99 gm of copper was recovered.

Fig. 7 Material balance



Efficiency

The metal extraction efficiency was calculated using the equation number (iii)

$\% \eta = (A - B) / A \times 100 \%$ … (iii)

Where,

η = % Cu Recovered

A= Presence of Cu in the initial sample

B = Residue of the Cu after performing Electrolysis

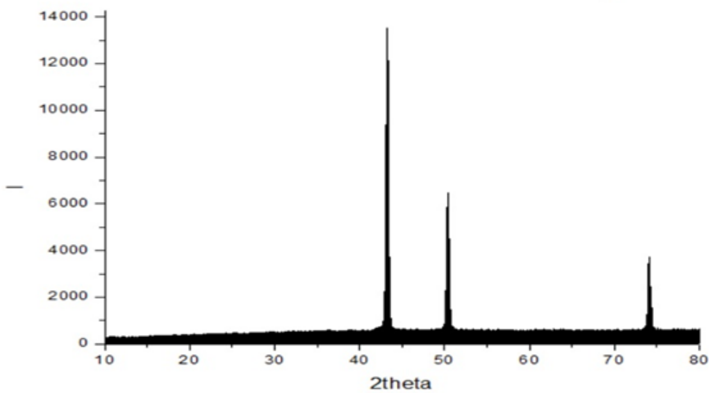
Equation no. 3 gives Cu extraction rate of 99.27% for almost both the cases.

Characterization

The powder obtained by performing the electrolysis is collected from the cathode chamber using a brush. The collected powder was dried at 80^0C for 8 hour. After drying the sample was tested for copper by AAS and electrolyte was also tested for remaining copper as shown in Figure 5 (a) and (b).

The powder was further characterized by XRD (X-Ray diffraction) using Bruker D8 Advance DA VINCI fully Automatic Powder X-ray Diffractometer System as shown in Fig 6.

Fig 6: XRD Analysis of extracted Powder



Different peaks of metallic copper were observed at 2theta namely 43.6, 50.7 and 74.45 which represented (111), (200) and (220) planes of face cantered cubic crystal structures of copper. IT confirms the purity as well as availability of copper in the powder recovered from electrolysis.

Conclusion

The process proposed here is a novel and energy efficient. Parameters like electrodes and electrolytes were optimized and temperature of 60^0C and 300 rpm of stirring temp of acid was proposed as the best possible combination to extract copper. Three combinations of electrolytes were used to check the better leaching and extraction efficiency where it is concluded that use of H_2SO_4 , HCl and H_2O_2 gives better extraction efficiency when Copper as a anode and cathode being used . In this process, 99.27 of Cu was extracted anywhere with 99% purity was determined.

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